

mechanism), the question as to which is preferred--wireline or wireless access service--cannot be answered.

If, as many believe, the NII only contemplates socially efficient access to narrowband voice and data services, then wireless technology is probably preferred for dedicated subscriber connections to the wireline intercity PSTN. Notwithstanding the fact that wireless access costs are lower, the real bonus for the consuming public from this scenario is portability.

If, however, broadband service, especially bandwidth on demand, is added to the narrowband mix for the NII, then wireline access technology is the winner. Interestingly, the Telecommunications Act of 1996 specifically calls for a universally available and affordable (ha, ha) switched broadband network infrastructure. It remains to be seen if the government sticks to the letter of the law when it discovers the price tag.

There is an interesting irony which flows out of this discussion: acting in their own business interests, wireless access network providers of all types, narrowband and broadband (e.g., wireless cable and satellite services), would not want to back a definition of service for the NII that included broadband or interactive multimedia capability. If they did, the winner in the race to be the infrastructure network provider would be wireline access.

By promoting a narrowband infrastructure, narrowband wireless access providers are clearly the least cost alternative. Broadband wireless access alternatives would also become the least cost alternative for their traditional (huge) niche market--distributive video service.

Thus, if service cost is the issue for the NII, and if policy makers envision bandwidth on demand as a long term infrastructure imperative, integrated two-way broadband services are best provided by wireline operators (e.g., cablecos and telcos). In this scenario, even though the role of wireless access services in the NII is not a dominant one, the indisputable convenience aspects of portability coupled with the affordability of new wireless technology, will assure that the mass market will still be served by the interconnected adjunct networks of wireless access operators.

This conclusion leads to another interesting twist for the public policy stance of the wireless industry regarding the NII. The bottom line for wireless technology, whether or not it is preferred by policy makers for the NII, is that it will be present and popular in the mass market. Considering this inescapable conclusion, and the private sector's general distrust of government involvement in an otherwise competitive business, wireless network operators of all stripes might consider it a blessing that they are not tagged as the vehicle for driving onto the public information superhighway.

#### 5.4 Capital Recovery and Financing Prospects

Given the cost data in tables 5.1 and 5.2, it is useful for purposes of illustration to point out what is implied for the demand side of the capital budgeting equation. As a rule of thumb, for every \$1,000.00 (\$1) of per subscriber network access line upgrade costs, fully \$14.00 (\$.014) per month of additional revenues per household served would be required to allow for full capital recovery of the original investment costs over a ten year discounted payback period at a 12% rate of return. This hypothetical includes the rather heroic assumption that new revenues would begin flowing immediately upon completion of the network construction, which is why the cost and implied capital recovery estimates represent a best case for cash flow analysis.

Table 5.3 provides a rough cost summary, and estimates of the associated construction timelines, for deployment of mass market broadband network upgrades for cablecos and telcos along with how much new sales revenues per month each of them would require from every single household passed by the broadband network. (Note that passing a home does not necessarily mean that the home has subscribed.) The numbers are cause for alarm if one is planning to go it alone in the face of stiff competition from both integrated and non-integrated infrastructure network alternatives.<sup>4</sup>

Table 5.3

Estimated upgrade costs for cable and telephone networks

	The next generation...		...and beyond	
	Cable (Fiber optics and coaxial cables)	Telephone (Fiber optics and coaxial cables)	Cable (Two-way fiber and coaxial cables)	Telephone (Entirely fiber-optic network)
Cost to install* \$1,500-5,000	\$50-300	\$1,500		\$1,000-1,500
Monthly revenue** \$20-35	\$1.40	\$10-20		\$14-17
Time frame years	3-10 years	5-10 years	10-20 years	10-30
Services	-Telephone -Data -Cable TV	-Telephone -Data -Cable TV	-Telephone -Data -Cable TV -Two-way	-Telephone -Data -Cable TV -Two-way

		video - High- resolution TV	video -High- resolution TV	
Overall cost	\$5-30 billion	\$75-150 billion	\$100-150 billion	\$150-500 billion

\* Per subscriber.

\*\* Extra monthly revenues per subscriber needed to justify the investment.

The column in table 5.3 labeled "The Next Generation" provides a range of likely costs for upgrading basic cableco and telco analog networks to provide one-way broadband services in the case of telcos, and two-way narrowband telephone services in the case of cablecos. This basically puts cablecos and telcos in a position to compete with one another on a more or less equal footing for integrated service to households. While table 5.3 indicates that cablecos have a tremendous cost advantage in the near term, when considering the costs of network upgrades for integrated service offerings it is important to keep in mind that there is little, if any, positive cash flow opportunity from providing traditional local telephone services. In the case of long distance service, the costs of interconnection to the PSTN are also substantial. Thus, as expected, we do not observe cablecos scrambling into this market (despite grandiose announcements to the contrary which appear from time to time in the trade press).

The right side of table 5.3 presents the costs and implied capital recovery requirements for second generation cableco and telco network upgrades to provide two-way broadband service capability. Notice that here the higher end of the cost range for cableco network upgrades is nearer to the lower end of the range for telcos. This makes the ultimate choice between the "passive" non-switched network architecture preferred by cablecos and the "active" switched architecture preferred by telcos a tougher call for cablecos' long term capital budgeting strategy.

Based on this data it is clear that, except for narrowband ISDN and local cable network two way interactive services, it is very costly indeed for any of these companies to go it alone in building the types of integrated multimedia networks for the mass market that are contemplated in the popular press and that are the objective of national infrastructure policy.<sup>5</sup>

Thus, in a sense, the race is on, at least on paper; and, in a sense, it isn't. Who wants to go first to wire up America with broadband?

Based on the cost data in table 5.3, even under the heroic assumptions of quick mass market deployment, the additional per household monthly revenues required to pay for the original investment is staggering considering the base of per household revenues spent on telecom service today. The average household in the US spends about \$45 per month on telephone services, and about \$25 per month on cable television services. Advertisers pay another \$25 per month per household to support over the air broadcasting, or so-called "free" TV, and there is another \$7 per month for broadcast radio.

Thus, in total, not counting what an average household spends on electronic devices, there is about \$100 up for grabs in a competitive marketplace. This amount is not growing very much at all, and neither is household disposable income. In fact over the last decade, the percentage of household income spent on telecom services has been flat at about 2%. The percentage of household income spent on cable TV service has also been flat in recent years now that the huge growth rates have begun to reach a market saturation point. Per household broadcast media revenue has been flat or slowly declining.<sup>6</sup> However, there are other potential revenue streams involving video media like movies, video tape and video game rentals and sales, which could add another \$20B in potential revenues. Revenues from information and transaction services, like home shopping, home banking, and other advertising services also exist, but there is no solid data on the market potential for such new services. It is reasonable to assume, however, that these are potentially substantial. Witness the very rapid growth of direct mail advertising which is now estimated at \$20B annually and is continuing to grow.

Overall, the current demand and revenue data from the telecommunications sector is indicative of the uphill battle faced by a competitive service provider of two way residential broadband network services. New revenue growth is always going to be subject to the ability of households to afford to pay for fancy new services and the terminal devices which support them. What's more, current revenue streams are supporting the payback for old and current capital investments and may not be immediately available to fund new construction budgets if alternative investments are more attractive.<sup>7</sup> The bottom line is that, unless an integrated broadband telecom network operator is allowed to freely pursue all revenue opportunities, including partnering with other service providers to save on new construction costs, it is very difficult to justify mass deployment of the new broadband to the home technology.

Even the telcos' own financial simulations for public broadband networks are pessimistic. Telephone company studies indicate discounted payback periods for video dial tone network upgrade alternatives ranging from 6-7 years for mediumband systems, with limited functionality and bandwidth, to 12-15 for more advanced broadband systems.<sup>8</sup> This even assumes some rather aggressive demand assumptions--on the order of 40% subscribership to a host of new services within 10 years.<sup>9</sup>

The investment banking community's researchers have examined the available data and it is apparent that they are not willing to accept the entire risk for capitalizing new broadband infrastructure ventures. They will only consider such high price tag projects when the borrower provides the lion's share of financing. Even then, the coupon rate for external bonds is very high, and will potentially be coupled with a demand for an ownership stake (e.g., stock warrants). This is why the only large scale projects are primarily financed by internal sources of funds from the deep pocketed incumbents like telcos and cablecos.<sup>10</sup>

In press announcements the major industry players have "committed" (on paper) to major network infrastructure investments. To date, the RBOCs alone have stated their intentions to spend about \$60B in broadband PSTN investments.<sup>11</sup> The major long distance companies, including AT&T and MCI, have announced similar amounts. The cablecos, following suit, have announced many billions of dollars for digital broadband infrastructure investments. Lately, the real strategies of the long distance carriers have emerged. Rather than invest billions building a local digital network infrastructure, the long distance companies have vigorously lobbied state and federal regulators to force the incumbent telephone companies to lease capacity and resell their local network connections at discounted rates. No one has really committed to spending the amounts of money which building a nationwide network infrastructure would require, and, with so many announcements, it is likely that there is a lot of market signaling going on. Most likely, some of the major "commitments" are really just a repellent to scare future rivals enough that they do not ultimately take the investment plunge, lest there prove to be a first mover advantage after all.

Most of the financing for new *personal communications service* (PCS) ventures has required the backing of deep pocketed incumbents as well. Smaller wireless infrastructure projects, including wireless cable and digital satellite systems, have been having trouble finding external financing. Only recently have the RBOCs shown significant financial interest in wireless cable investments. They usually require a significant equity stake, or purchase an existing system outright (or the license where a system is not yet built).

The increasing competition being allowed by regulators in traditionally monopolistic markets is largely responsible for the riskiness of new broadband infrastructure investments. Recent attempts by large industry players to broaden the base of external investors in new infrastructure projects like global digital satellite systems does not bode well for financing infrastructure investments, even such relatively small ones such as digital satellite systems. Two of the leading contenders in the race to deploy satellite systems, Globalstar and Iridium, have both failed recently to attract investor interest in recent bond offerings--even at fairly high coupon rates.<sup>12</sup>

Thus, even though there is a clear technological trend toward industry convergence, based on the twin facts that broadband infrastructure investment projects involve extremely expensive up front costs and the industry is becoming increasingly competitive, it is not likely that private enterprise will be willing to take the financial plunge anytime soon.

# **The Effect of Cellular Service on the Cost Structure of a Land-Based Telephone Network**

**by**

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**October 22, 1996**

**Abstract:** While economies of scale and scope have been extensively studied in traditional telephone networks, thus far little academic attention has been paid to the effect of cellular communications, which is one of the most rapidly growing segments of the telecommunications system. We use LECOM – our Local Exchange Cost Optimization Model – to generate data representing an optimal telephone network before and after the introduction of a cellular network. We derive geographic data from Statistics New Zealand's meshblock data. Our cost data for network components are "typical" North American annual costs. Our initial results suggest, somewhat intriguingly, that there may be potential gains to more widespread introduction of cells in some rural areas, particularly those characterized by customer populations clustered along major roads.

## INTRODUCTION.

LECOM, the Local Exchange Cost Optimization Model, has been in service since 1991 when it was first developed by under a grant from the National Regulatory Research Institute of Ohio State University. LECOM operates by optimizing a telephone network on a map by choosing the technology mix, number of facilities, and locations of the facilities within the area that minimize the annualized cost of service. The software has (so far) been at the core of three published articles (Gabel and Kennet (1993a), Gabel and Kennet (1993b), and Gabel and Kennet (1994)), a published research monograph (Gabel and Kennet (1991)), and at least three scholarly presentations or works in progress (Kennet and Gabel (1995), Kennet, Heyen and Gabel (1995) and Gasmi and Sharkey (1995)).

The original version of the software, which is in the public domain, could be used to determine the economic crossover point between different type of wireline facilities (e.g., copper, digital line carrier on copper, or digital line carrier on fiber). The new version of the software identifies the economic crossover point between landline and wireless networks. The model takes into account the high usage costs but low customer access costs of wireless technology, and explores the economic trade-off with the high customer access/low variable cost structure of wire networks.

While economies of scale and scope have been extensively studied in traditional telephone networks, thus far little academic attention has been paid to the effect of cellular communications, which is one of the most rapidly growing segments of the telecommunications system. We use LECOM to generate data representing an optimal telephone network before and after the introduction of a cellular network. We derive geographic data from Statistics New Zealand's meshblock data. Our cost data for network components are "typical" North American annual costs. Our initial results suggest, somewhat intriguingly, that there may be potential gains to more widespread introduction of cells in some rural areas, particularly those characterized by customer populations clustered along major roads.

The paper is organized as follows. In Section I, we briefly describe the LECOM model for a land-based exchange network. We also describe how LECOM incorporates

geographic data of the sort available from national statistical agencies. In Section II, we describe how we incorporate a model of cellular telephony into LECOM. Finally, in Section III we give our results for New Zealand and provide some discussion.

## **I. THE LECOM OPTIMIZATION MODEL AND ITS DATA REQUIREMENTS**

There are three primary types of facilities found in the local exchange carrier's network: the local loop, switching, and trunking. The local loop is composed of facilities that provide a signaling and voice transmission path between a central office and the customer's station. The central office (or wire center) houses the switching machine that connects a customer's line to either another customer who is served by the same switch, or to an interoffice trunk. Calls between central offices are carried on trunks.

LECOM operates by first determining an area's dimensions and customer usage levels from user data. LECOM then searches for the technological mix, capacity, and location of switches that minimize the annual cost of production. This is equivalent to minimizing the present worth of capital, maintenance and tax expenditures (see Freidenfelds (1978)). The locations of the switches are optimized by the nonlinear derivative free routine proposed by Nelder and Mead (1965).

The cost optimization is based on the cost of various technologies that are currently available to local exchange carriers. See Gabel and Kennet (1991), (1994) for details.

### ***Local Loop Topology***

Telephone engineers break the service territory of a central office into discrete regions, called serving areas. Since the early 1970s, serving areas have been the basic building block used to determine the most economical choice of facilities.<sup>1</sup> The facilities that compose the serving area are commonly referred to as the distribution plant. A serving area typically includes 350 to 600 subscribers. Feeder plant connects the service

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1. Bell Telephone Laboratories, *Telecommunications Transmission Engineering: Networks and Services*, 2nd edition, 40-44; and John Freidenfelds, *Capacity Expansion: Analysis of Simple Models with Applications* (New York: North Holland, 1981), 238.

area to the central office. In turn, distribution plant connects the feeder plant to the subscriber, and is often referred to as the distribution plant.

Figure I depicts a typical serving area. A backbone cable runs from the serving area interface and street cables--or legs--branch off the backbone at equal intervals. Each time street cables branch off, the backbone cable tapers down.<sup>2</sup>

The same design principle is used with feeder plant. Feeder cable runs from the central office and is connected to a number of branch feeder cables. This design, known as the "pine tree geometry," minimizes the cost of outside plant facilities.<sup>3</sup>

Consistent with engineering practices, we have assumed that the main feeder cables leave the wire center in four directions.<sup>4</sup>

### ***Interoffice Traffic***

Exchange traffic either may originate and terminate on the same switch (intraoffice traffic), or go between central offices (interoffice traffic). As shown in Table I, the proportion of calls that originate and terminate on the same switch varies between communities. In rural areas, all customers in an exchange typically are served by one switch. Consequently, interoffice exchange calls from small towns occur only where extended area service has been established.

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2. J. A. Stiles, "Economic Design of Distribution Cable Networks," *Bell System Technical Journal* 57 (April 1978): 945.

3. Bell Laboratories, *Telecommunications Transmission Engineering* 62. The use of the pine-tree topology provides an approximately 5 to 30 percent saving over a bush architecture.

4. Bridger M. Mitchell, "Incremental Costs of Telephone Access and Local Use," Rand R-3909-ICTF (July 1990): 17.

**Table I**

Intraoffice Calls: Proportion of <u>Total</u> Calls	
<u>Community</u>	<u>Percent</u>
Rural	66
Suburban	54
Urban	31

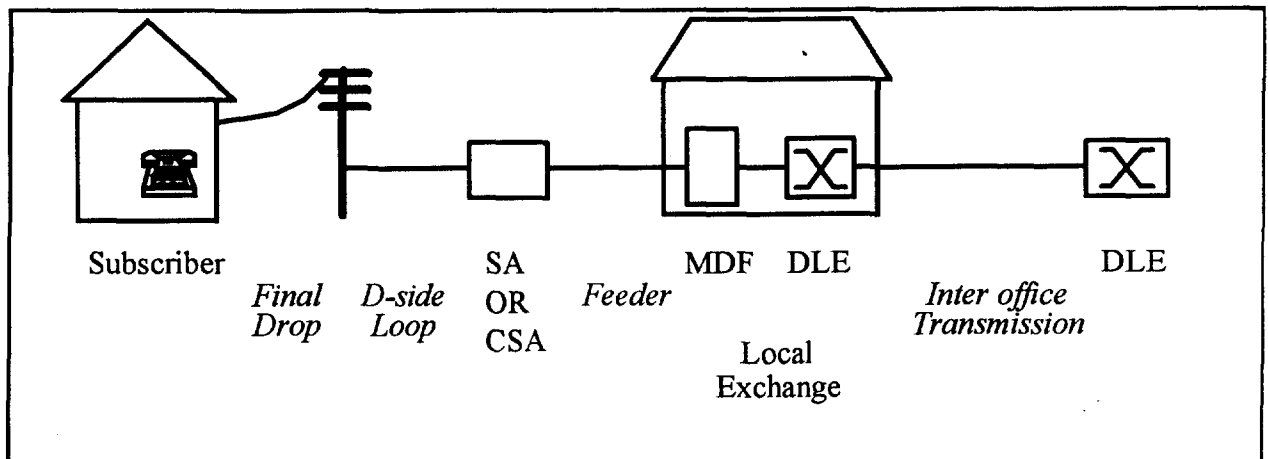
Source: R.F. Rey, ed., Engineering Operations in the Bell System (Murray Hill, N.J.: Bell Laboratories, 1983, second edition), 125.

In larger cities, the local exchange company typically deploys more than one switch. Suburban customers are less likely than urban customers to place an interoffice call because their primary community of interest is in nearby stores and among neighbors, locations often served by the same switch. Urban customers, on the other hand, are more likely to need to call customers served by a different switch.

Traffic studies show that when an interoffice call is placed, there is a greater likelihood that it will be placed to a customer served by a nearby switch rather than a distant machine. For example, a subscriber placing an interoffice call from downtown is more likely to call another downtown customer than a suburban subscriber.

We have constructed LECOM to take into account business customers being more likely to place interoffice calls that mostly go to nearby switches. The percent of intraoffice calls is an increasing function of the number of customers terminated on the customer's host switch divided by the number of switched customers in the city.

**Figure II: Components of the Typical Access Network**



CSA= Carrier Serving Area

D-side = Distribution Side

DLE = Digital Local Exchange

MDF = Main Distribution Frame

SA = Serving Area

The largest part of the investment made by a local service network operator is for its local loop facilities. Within the local loop there are certain fixed costs associated with laying cables which are independent of the capacity of the cable, that is the number of pairs of cable in the cable sheath (see Column C in Table II below). Within each cable sheath, there is a variable cost component that is a function of the number of customers being served (see Column B in Table II below).

An incremental cost study measures the change in cost which is associated with the change in the level of demand. When estimating the change in loop costs, the appropriate economic question that needs to be addressed is whether or not there would be a different number of cables if the level of demand were to grow. If the answer to this question is affirmative, then the estimate of the change in loop costs should include the change in fixed costs associated with laying cables (i.e., site preparation and excavation, leases, etc.). If the answer is negative, the estimate of the change in loop costs should reflect only the cost of using the same number of cables but with greater capacity, that is different size cables, not additional cables, and should not reflect any change in the fixed costs of laying cables.

These cables that connect customers to the central office are costly to install, largely because of the labor cost of installing the facilities. Table II identifies the expense of installing 100 meters of aerial cable.<sup>5</sup> By law, buried cable is mandated in New Zealand. I am presenting data for aerial cable because it illustrates the cost structure of installing cable. The same cost structure exists for buried and underground cables.

**Table II: Investment Per 100 Meters of Aerial Copper Cable**

Investment Per 100 Meters (NZ \$)					
Cable Size # pairs per sheath	Material (cable)	Installation	Equipped, Furnished, and Installed	Average Investment Per Pair	Incremental Investment per Pair
(A)	(B)	(C)	(D) = (B) + (C)	(E) = (D) / (A)	(F)
100	\$272.83	\$378.94	\$651.77	\$6.52	\$6.52
200	\$510.30	\$378.94	\$889.24	\$4.45	\$2.37
300	\$752.82	\$378.94	\$1,131.76	\$3.77	\$2.43
400	\$1,000.39	\$378.94	\$1,379.33	\$3.45	\$2.48

While the number of observations in the table is small, it is representative and can still be easily summarized with linear regression analysis:

$$\begin{aligned}
 \text{Investment} &= \beta_1 + \beta_2 * \text{Cable\_Size} + u \\
 &= 406.72 + 2.43 * \text{Cable\_Size}
 \end{aligned}$$

5. Kenneth P. Helgeson, Director of Engineering and Construction, NYNEX, *Rebuttal Testimony—evidence submitted to the Maine Public Utilities Commission*, Docket 94-123/94-254, 13 (January 13, 1995). The data in Table II only include the investment in the aerial cable—the cost of the pole is not included. An exchange rate of \$1.51 NZ/\$1 US was used to develop the table.

Table II assumes 100% utilization, a fill level that is not achieved in practice. Typically utilization runs around 65% and, therefore, if utilization were taken into account the average and incremental costs would be higher by a magnitude of  $1/.65 = 1.53$ . The incremental investment per pair is derived by dividing the additional cost of a larger cable by the change in the size of the cable.

The ordinary least estimate of  $\beta_1$ , NZ\$406.72, is the estimate of the fixed investment cost of installing 100 meters of aerial cable. The slope term,  $\beta_2$ , NZ\$2.43, is the estimate of the incremental investment cost of installing one additional pair of cable, 100 meters in length.

The capacity of a copper cable runs up to 4,200 pairs. The fixed cost of the cable is only part of the TSLRIC of residential service if either of the following two conditions hold true: (1) there are no business customers sharing the cable; or (2) the number of customers served in an area is greater than 4,200 pairs, and the elimination of the residential customers reduces the number of cables that must be installed<sup>6</sup>

#### **B. The Local Switching Machine and Electronics in the Local Loop**

In the previous section, I addressed the economics of deploying copper cable to connect customers to the central office. Other facilities used in wireline networks are typically less labor intensive, but they nevertheless involve substantial fixed costs. For example, when a digital switch is deployed, a sizable fixed cost is incurred. In order to run a digital switch, the local service network operator must incur certain start-up costs, for example the central processor and associated software required for "plain old telephone service" (POTS), as well as certain maintenance and test equipment expenses. These start-up costs are included in the estimate of the change in costs when the addition of residential customers increases the number of switching machines.

When fiber optics are deployed in the loop, there are also significant start-up costs that may not be part of the TSLRIC of residential service. The data in Table III assume that there are 1,000 customers at the remote site which houses the electronics.<sup>7</sup>

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6. If fiber cable is being used in the feeder plant, it is unlikely that the elimination of residential customers will change the number of fiber cables that are deployed (due to the high capacity of the fiber cable).

7. The investment and capacity data was obtained from New England Telephone, *Maine Marginal Cost Study*, Docket 92-130, Part 3, Tab A, Section IV, Table 2.1. Aerial

fifth the cost of installing cables.<sup>9</sup> The multiplexers on interoffice facilities, like those used for local loops, provide flexible amounts of capacity depending on the speed of the multiplexer and the extent to which the equipment is fully loaded with boards that are used to accelerate the speed of the digital signals.

#### **D. Summary Comment regarding the cost structure of wireline networks**

There are very few customer-specific investments on a wireline network. Except for the line card on a digital switch, and the pair of wires that are dedicated to a subscriber, there are few facilities that are not shared by multiple customers.

The first cost of the line card varies greatly depending on the manufacturer of the switch. In this study we are estimating costs using a version of LECOM that models that assumes that only Northern Telecom switches are deployed on a wireline network. The cost of terminating a line on a Northern Telecom switch is high relative to other digital switches.

The first cost of the pair of wires that provide access to the network is a function of customer density and the length of the loop. The cost of the wire has elements of both a direct and shared cost. The cost of the pair of wires is directly attributable to the subscriber. On the other hand, the capitalized labor installation cost is a shared cost that may or may not be independent of an individual customer connecting to the network. To the extent that capacity is exhausted in a cable, the capitalized labor cost is directly attributable to individual subscribers. However, where there is no congestion, the installation cost is only part of the incremental cost of service when the entire demand for loops is considered (as with total element long-run incremental costs).

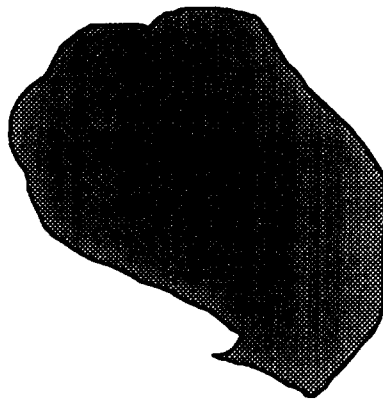
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9. Timothy Tardiff, "Economic Evaluation of Version 2.2 of the Hatfield Model," *NERA*, (July 9, 1996). Prepared for GTE in "Rulemaking on the Commission's Own Motion to Govern Open Access to Bottleneck Services and Establish a Framework for Network Architecture Development of Dominant Carrier Networks," California Public Utilities Commission, R.93-04-003, 6. The data presented in Table 1 suggest that the material component is larger than twenty percent. The difference in percentages may be explained in part by the use of buried cable in California. Installing buried cable is relatively more labor intensive than hanging aerial cable on poles.

### *Incorporating Geographic Data into LECOM*

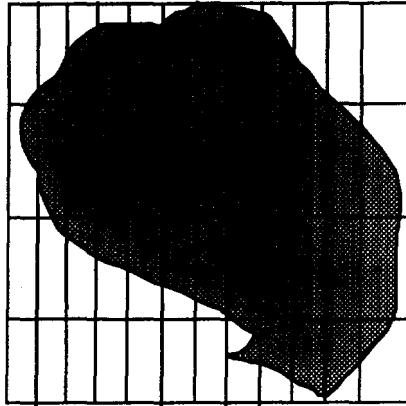
We begin the discussion by describing a geographic region; for example, see the region below. The region is represented by coordinate data and population associated with the coordinates. Statistics New Zealand has coordinates for the perimeters of meshblocks as well as business employee data; this level of detail is not available from the U.S. Census Bureau, which only makes available centroids of Census blocks and household population.

## Geographic Region



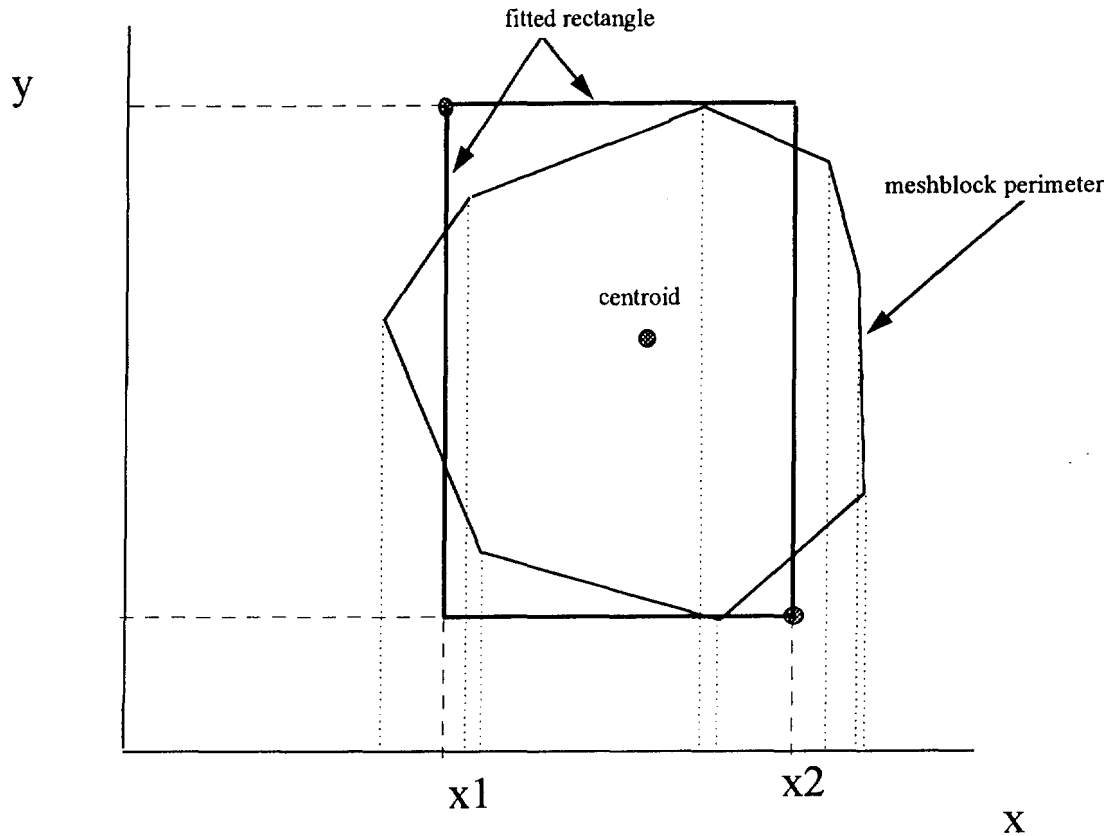
The software finds the *rectangular hull*, or the smallest rectangular region that contains the entire geographical region of interest. LECOM then grids the region, using grid dimensions defined by the user. Typically, we have used grid sizes of 12 kf by 2 kf, ensuring that customers are no more than 13 kf from serving area interface electronics. CBGs whose centroids fall within a gridblock are joined to form “serving areas.”

## Geographic Region with 12kf x 2kf grid ("rectangular hull")



The next issue is the size and shape of serving areas. LECOM needs to calculate a rectangular approximation to the serving areas. If we are using U.S. CBG data, not much can be done except on an ad hoc basis, because the data contain only centroids. Thus, serving areas become equivalent to gridblocks. If better data, such as the New Zealand meshblock data, are used, LECOM has a method to deal with perimeter information.

Suppose there were only one Census block in a gridblock. LECOM first locates the centroid, then the average x-coordinate of all perimeter vertices to the left of the centroid and the average x-coordinate of all perimeter vertices to the right of the centroid. These points define the east-west dimension of the fitted serving area; the north-south dimension is defined by the maximum and minimum y-value from the perimeter data.



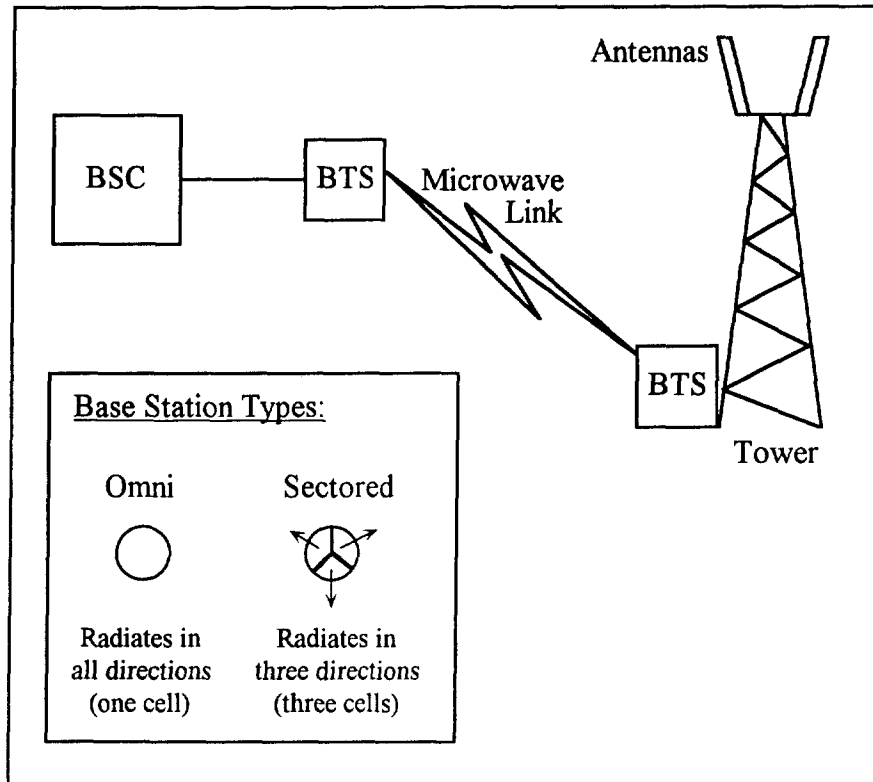
Fitted Rectangle

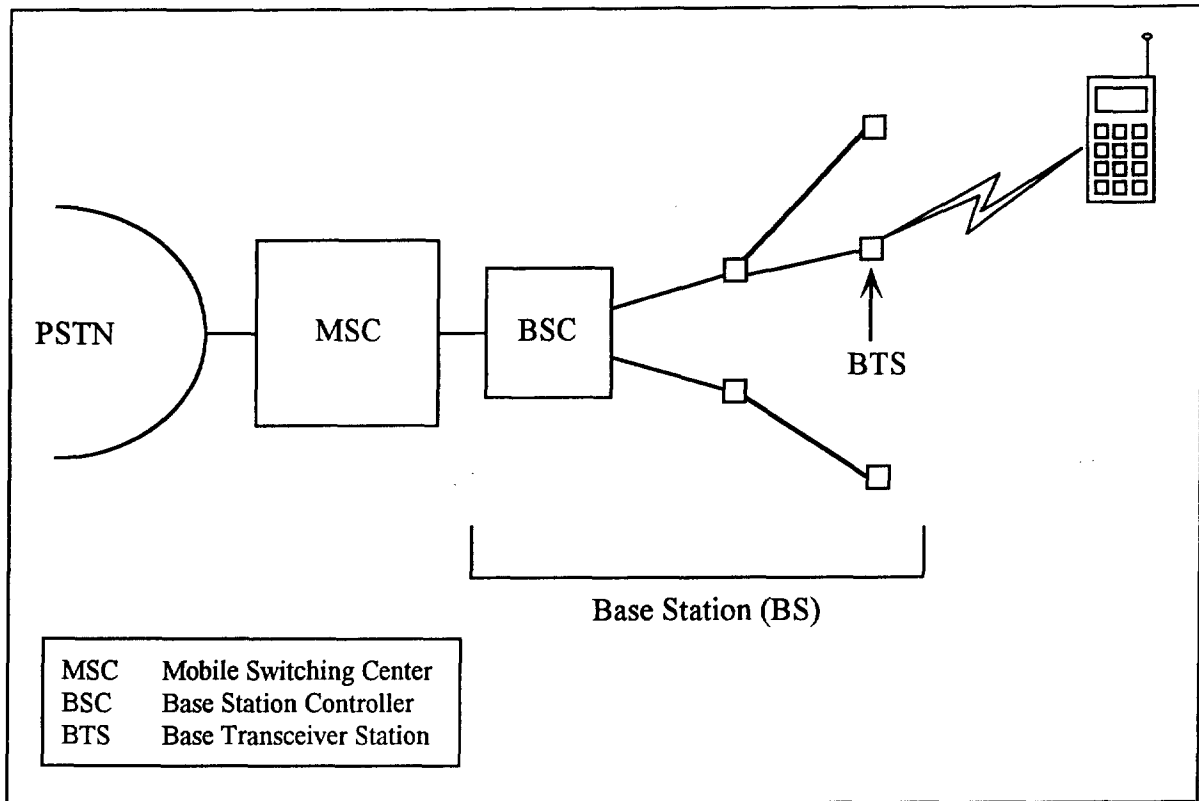
This process is repeated the necessary number of times until all meshblocks are incorporated into serving areas.

## II. Incorporating Wireless Stations into LECOM

We now turn to a description of wireless network technology. By wireless we mean the ability to secure two-way communications at a distance without the use of wires. Figure III illustrates the equipment that is involved in a wireless network.

# Figure III: Radio Base Station





In a GSM network, base station transceivers (BTS) are located approximately 20 to 30 kilometers apart. Ulysses Black provides the following description of the equipment required for a GSM network:<sup>10</sup>

The interface with the mobile station (MS) is provided through the base transceiver station (BTS). These two components operate with a range of radio channels across an air interface. The BTSs are controlled by the base station controller (BSC), which is a new cellular network element that was introduced by GSM. It is responsible for the hand over operations of the calls as well as for controlling the power signals between the BTSs and MS--thus relieving the switching center of several tasks.

The mobile MSC is the heart of the GSM and is responsible for setting up, managing, and clearing connections as well as routing the calls to the proper cell. It provides the interface to the telephone system as well as provisioning for charging and accounting services.

GSM requires the use of two databases called the home location register (HLR) and visitor location register (VLR). These databases store information about each GSM subscriber. The HLR provides information on the user, its home subscription base, and the supplementary services provided. The VLR stores information about subscribers in a particular area. It contains information on whether mobile stations are switched on

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10. *Emerging Communications Technologies*, (Prentice Hall, 1994): 344-45.

or off, and if any of the supplementary services have been activated or deactivated.

We are interested in modeling the cost of using wireless network to serve areas that are expensive to serve using traditional wireline facilities. Therefore we have modeled a fixed mobile network. In a fixed mobile network, a wireless network is used to connect the wiring in a household with a switching machine. Within the household, a traditional handset can be used. An antenna on the dwelling structure transmits and receives radio signals with the closest base transceiver station.

In LECOM, we have modeled the tower locations as an argument to the cost function, with the Base Station and MSC centrally located. Serving areas are "attached" to the tower according to a binary function: cost of attachment is zero if the entire serving area is within 15 km (Cartesian distance, rather than rectangular distance) of the tower, machine infinity otherwise. Thus, the tower becomes a technology alternative to the host-remote configuration previously modeled in LECOM. We have assumed that each region modeled has its own MSC. For the purposes of this exercise, we have further assumed that all interoffice traffic is carried by microwave.

#### *Cost Data for Wireless Network*

The equipment required at the customer's location is quite expensive. In a recent study undertaken for AT&T and MCI, Hatfield Associates and Economics and Technology suggest that the investment is approximately US\$300 per household. Because of this expensive item, they conclude that "[a]t this level, it is evident that cellular radio is an unlikely replacement for the existing LEC telephone service."<sup>11</sup> While we find the assumption of a \$300 investment per household to be reasonable, the purposes of this

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11. *The Enduring Local Bottleneck: Monopoly Power and the Local Exchange Carriers*, Economics and Technology and Hatfield Associates, 1994, 91. A similar conclusion has been reached by Prudential Securities: "While we don't believe wireless will develop into a substitute for wireline access, it should complement the rapid growth and development of wireline networks." Prudential does believe though that in rural areas, wireline networks may have a cost advantage. "Broadband Wireless," *Prudential Securities*, (April 19, 1996): 8; quote, 18.

paper is to evaluate the cost savings associated with using a fixed mobile network. As we show below, despite the assumption of a large customer specific investment, we still find that fixed mobile technology provides savings relative to a wireline only network.

The antenna on the customer's household communicates with the nearby base transceiver station. The cost structure of the base transceiver station is quite different than that of the loop plant for a wireline network. The cost of serving a customer on the wireline network is very much affected by the distance between the customer and the central office. Distance is still important on a wireless network; the farther a customer is from a central office the more equipment is required for transmitting the call from the BTS to the MSC. This distance sensitivity for the wireless technology is not unlike the distance sensitivity for the feeder portion of a wireline network.

There are two important distinctions though between the wireline and wireless network. First, the cost of the link between the household and the BTS is independent of distance. It does not matter if the customer is located one or eleven kilometers from the BTS, the cost of the customer specific facilities is identical, \$300.

Second, unlike the distribution facilities on a wireline network, congestion can and does occur on wireless networks. The number of voice channels that can be served by a BTS is constrained by the available radio spectrum. Depending on if omnidirectional or sectorized cells are used, the capacity of the BTS can vary, but regardless is small relative to the capacity of wireline facilities.<sup>12</sup> Because of this capacity limitation, if the amount of traffic in a geographical area exceeds the capacity of a BTS, the service area of the tower must be reduced (split). Hence while there are large fixed costs associated with erecting a BTS, the cost must be duplicated where the capacity of a single tower is exceeded. Hence the "distribution" portion of the wireless network is traffic sensitive, as is the, in part, the "feeder" section of the wireless network. As the busy-hour usage increases, the supplier

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12. See, for example, William C.Y. Lee, *Mobile Communications Design Fundamentals*, second edition, Wiley Series in Telecommunications; and Gregory P. Pollini, Kathleen S. Meier-Hellstern, and David J. Goodman, "Signaling Traffic Volume generated by Mobile and Personal Communications," *IEEE Communications Magazine*, June 1995, 60-65.

must install additional capacity on its microwave feed from the BTS to the MSC, or rent additional capacity from the wireline network supplier.

Our results below reflect the outcome of using LECOM to identify a network that minimizes the annual cash-flow requirement of a network that satisfies a given level of demand. Our demand level of 2.95 CCS per line is reflective of usage in a suburban or urban area.<sup>13</sup>

When determining the annual cash-flow requirement of a given network design, we make no assumptions regarding how many customers share facilities. Rather the extent to which a tower, BTS, or some other facility is shared by customers is determined by the capacity of the equipment, and radio spectrum,<sup>14</sup> as well the number of customers to whom it is cheaper to serve by wireless rather than wireline facilities. The model connects a serving area to the network with wireless facilities where the cost of using the wireless facilities is less than the cost of using traditional wireline technologies.

### **III. Results and Discussion.**

In Table IV we report average cost values for partially optimized networks for each of three regions of interest in New Zealand. There is an important caveat that must be made known up front before we can discuss these numbers. To facilitate the production of this paper, we limited the number of cellular towers that could be installed in each region to 12 in the case of Auckland-Hamilton and 20 in the other cases. In each of the three cases, the optimizing result included this maximum number of cellular towers, suggesting that relaxing the constraint may lead to lower average costs per line.

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13. For example, R.A. Skoog reported that in urban, suburban, and rural exchanges, the busy-hour CCS was respectively 3.1, 2.7, and 2.1. *The Design and Cost Characteristics of Telecommunications Networks*, Defendants exhibit number 2059, Table 5-4, *United States v Western Elec. Co.*, 592 F. Supp. 846 (D.D.C. 1984).

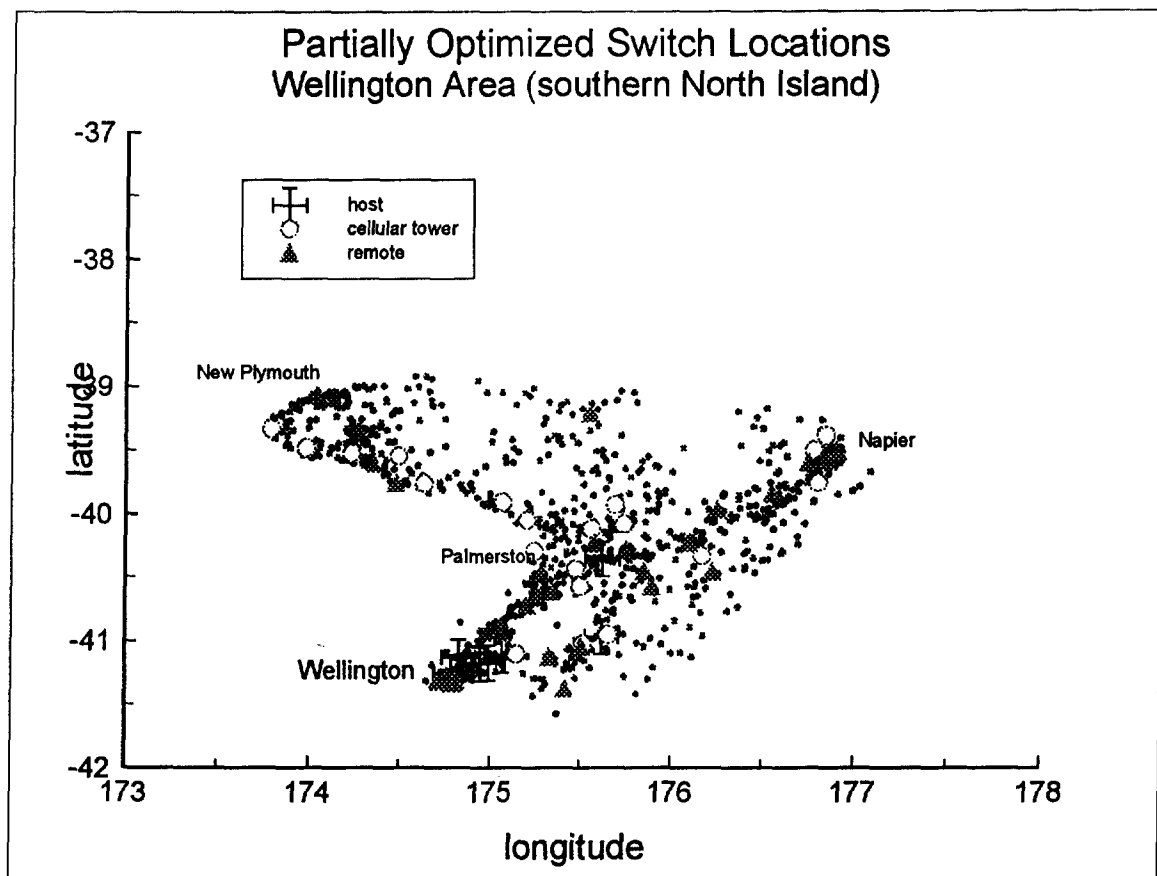
14. The cost of the radio spectrum has been included in our analysis as a fixed cost. The spectrum cost is part of the fixed cost of setting up a wireless network, but once incurred, is not included at the margin. Therefore the spectrum cost is part of our average cost estimates, but excluded from our marginal cost numbers.

The model also includes the cost of using microwave facilities to connect the towers to the base station controller.

**Table IV: Average Monthly Cost Per Line**

Region	Wireline Only (NZ\$)	Wireline Plus Cellular (NZ\$)
Auckland-Hamilton	54.62	52.54
Wellington	57.04	54.18
South Island	87.48	82.51

Given these caveats, we can still draw some conclusions. First, it would appear that fixed mobile cellular provides a cost-competitive alternative to wireline service in certain rural areas. As the map generated by LECOM below (Figure IV) shows for the Wellington area, this result applies along important rural highways, like the ones between Palmerston and Napier and between Palmerston and New Plymouth.



These results suggest that fixed mobile cellular meets the “average cost test;” that is, they provide service at a lower average cost than wireline infrastructure in the Wellington area of North Island.

We have been able to explore the Wellington region more deeply, both relaxing the constraint on the number of cellular towers and calculating incremental costs for both access lines and peak hour calling seconds. These results appear in Table V.

Table V suggests that not only is fixed mobile cellular competitive with wireline on an average cost per line basis, the incremental cost per line and per ccs is also competitive. These results are somewhat surprising because the traditional view is that mobile has a lower per line, but higher usage cost. We suspect that our results reflect that our mobile towers have been largely placed in rural areas. When busy-hour CCS traffic increases, additional electronic equipment is required, but there is no need for cell splitting. In rural areas, the placement of towers, relative to urban areas, is driven more by signal attenuation concerns and less by congestion.

With this caveat in mind, these results suggest that we may be observing a significant shift in the cost structure of telecommunications networks and that, as a consequence, the industry and policymakers must be prepared to confront a completely new set of parameters.

**Table V**  
**Incremental Cost Results for Wellington**  
**Fixed mobile cellular**

	<b>Per Year</b>	<b>Per month</b>
<b>MC(CCS)</b>	15.57074	1.297562
<b>MC(LINES)</b>	169.0122	14.08435

**Wireline only**

<b>MC(CCS)</b>	24.58594	2.048828
<b>MC(LINES)</b>	317.0019	26.41683